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HUMAN FACTOR PROBLEMS IN ANTI-SUBMARINE WARFARE

Technical Report 206-22

FURTHER STUDY OF PPI PIP SHAPES IN RELATION TO SONAR TARGET CLASSIFICATION (U)

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FURTHER STUDY OF PPI PIP SHAPES IN RELATION TO SONAR TARGET CLASSIFICATION (U)

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ABSTRACT

The significance for target classification of the pip shapes displayed by the SQS-23 sonar in comparison to those observed with earlier scanning sonars was studied for a large sample of echoes from submarine and nonsubmarine targets.

It was found that the descriptive pip shape categories developed for the earlier sonars were inadequate for describing the pips displayed by the SQS-23. This was particularly true for difference brightening and target centered display conditions.

Many of the pip shapes were found to be related significantly to target nature in a statistical sense. But, from a practical viewpoint, these relationships were not sufficiently dependable to warrant direct inferences about the target's classification. The most useful function served by pip shape continues to be the opportunity it affords to estimate the orientation of the target's major axis.

Important interactions were noted between the pip shape displayed, the target's nature, and the range scale in use on the PPI.

ACKNOWLEDGMENTS

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FURTHER STUDY OF PPI PIP SHAPES IN RELATION TO SONAR TARGET CLASSIFICATION (U)

I. SUMMARY AND OPERATIONAL IMPLICATIONS

Background

The value of the sonar PPI scope as a source of clues to target classification had been demonstrated in earlier research on the SQS-10/11 by Mackie and Kimmel (1954) and Harsh and Eady (1955). The displayed patterns of information were later found to be essentially the same for the SQS-4 (Gavin and Mackie, 1958).

No systematic investigation of PPI clues had been conducted since these early studies and it was felt, particularly with the advent of RDT sonars, that their meaningfulness for classification should be re-determined. Present classification procedure, and the logic of classification aids such as HHIP and MITEC, depend heavily upon recognition of pip shapes and axis angles. Incidental observation suggested that the display of these features had changed somewhat with RDT-modified and SQS-23 sonars, particularly when difference brightening and target centered display were employed.

Purpose

The present study had the following objectives:

1. To determine whether previously established pip shape categories were adequate for describing the pips displayed by RDT-modified and SQS-23 sonars.
2. If the answer to (1) were negative, to develop a new set of categories that would describe the displayed shapes adequately.

3. To determine the significance for classification of each new shape category found necessary and to determine if the old ones had continuing significance.

Method

Six experienced observers sorted large numbers of photographs of submarine and nonsubmarine target pips displayed by SQS-4, SQS-32, and SQS-23 sonars into a minimum number of exclusive shape categories. Where agreement among observers was lacking, additional sorts were made until essential concordance was achieved on the number and description of the categories. In general, inter-judge agreement was substantial. The meaningfulness of these categories was then investigated by examining the relationships between pip shape and target nature and, where the target was a submarine, between pip shape and target angle.

Results

1. The six difference brightening shape categories developed for the earlier sonars were found to be inadequate for describing the pips displayed by RDT and SQS-23 equipment. Judges agreed on the necessity for an additional four categories, making a total of 10 basic difference brightening shapes. Slight variations on the original sum brightening shapes were also found desirable although no fundamentally new shapes were found necessary.

2. Seven of the 10 difference brightening shape categories were found to be related significantly (in a statistical sense) to whether the target was submarine or non-submarine. However, the relationships often were inconsistent from one type of sonar to another and were not sufficiently reliable to place heavy dependence upon them for classification. Interactions between target range,

pip shape displayed, and target nature apparently played a substantial role in minimizing these relationships.

Five of the seven sum brightening shapes also were found to be significantly related to the nature of the target. Some of these relationships were strong enough to play an influential role in classification logic but others were believed to be the result of an operational artifact.

3. In those cases where the target was a submarine there was a substantial and logical correspondence between the major axis of the pip shape displayed and the orientation of the target in the sound beam. This occurred with sufficient regularity to make pip shape judgments useful in determining target aspect a key step towards successful target classification. However, many nonsubmarine targets also produced pip shapes having axis angle indications similar to those produced by submarines.

4. Strong interactions were noted, for both sum and difference brightening, between the pip shape displayed, range scale in use, centering mode and target nature. These interactions make it exceedingly difficult to make any generalizations concerning the pip shapes displayed and the classification of the target.

Recommendations

1. Training courses in target classification should emphasize the useful relationship between pip shape and the corresponding axis angle (implied aspect) of the target. More direct relationships between pip shape and target nature are heavily dependent on target range and the

display mode in use and should be expressed with caution.

2. The pip shape categories employed in this investigation represent better descriptions of the displayed PPI information than those previously developed. They should be incorporated into future training aids, instructor guides, student response forms, and PPI input panels of classification aids.

II. BACKGROUND OF THE STUDY

Investigation of Pip Shape

The earliest studies of sonar PPI pip shapes were accomplished jointly by HFR and NEL using SQS-10/11 sonar returns from a large and systematic sample of submarine and nonsubmarine targets. Investigation of pip shapes produced using sum brightening (Mackie and Kimmel, 1954) resulted in the 6-category classification scheme illustrated in Figure 1. In general the pips differed fundamentally in symmetry, number and compactness of components, whether or not a linear axis could be fitted through the components, and orientation of the axis with respect to the cursor.

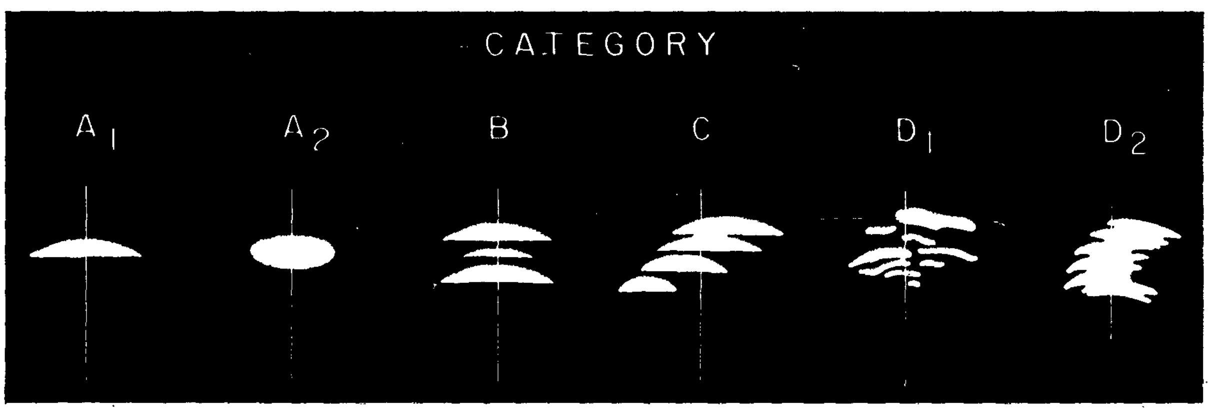

Figure 1. Sum brightening pip shape categories reported by Mackie and Kimmel (1954).

It was found that, with the exception of A_1, pips in each category had a differential likelihood of having been produced by submarine and nonsubmarine targets. Pips having "B" and "C" shapes were produced significantly more often by submarines while those having A_2, D_1 and D_2 shapes were more often obtained from nonsubmarine targets. It was also discovered that there was a correspondence between the aspect of the submarine target and the angle made between the cursor on the PPI scope and an imaginary long axis through the displayed pip.

In research on difference brightening pips conducted by NEL, Harsh and Eady (1955) developed a corresponding set of 6 pip shape categories. These, together with the classification significance associated with each category are shown in Figure 2. The logical (but not always observed) correspondence between the sum and difference categories is also indicated. The difference brightening shape E and EW, corresponding to sum shapes A_1, B and C could, of course, form any axis angle with the cursor, the designator itself not conveying this information.

The Use of Pip Shapes In Classification Aids

The first operational target classification aid (HHIP) was based on logic tables developed by Eady at NEL (1958). PPI inputs were to be made using difference brightening only and required discrimination among four basic shape categories (for details see Gavin, 1961):

1) DP (double pip) corresponding to sum brightening category A_1.

2) NE (non-elongated) corresponding to sum brightening categories A_2, D_1 and D_2.

3) E (elongated) corresponding to sum brightening categories B and C.

4) EW (elongated with wake) also corresponding to sum brightening categories B and C but requiring a more extended pip.

To further refine the input, an axis angle judgment was required for all pips displaying DP, E, or EW characteristics.

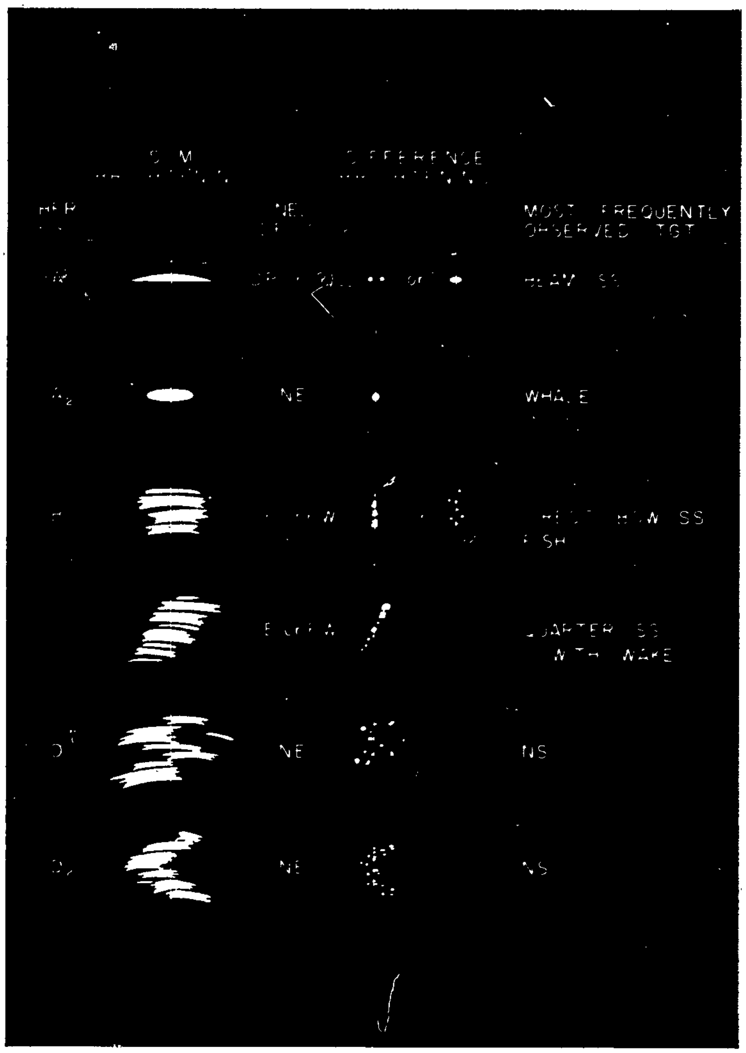

Figure 2. Corresponding sum and difference brightening pip shape categories reported by Harsh and Eady (1955).

After an extensive investigation of the classification clues presented by SQS-4 sonar, Mackie, Gavin and Parker (1959) recommended that classification procedure should emphasize seven shape categories that had been found to be (1) most significant from a classification viewpoint and (2) most reliably perceived by operators. This reduced set of shapes, together with the alphabetic designators given them at that time, are presented in Figure 3.

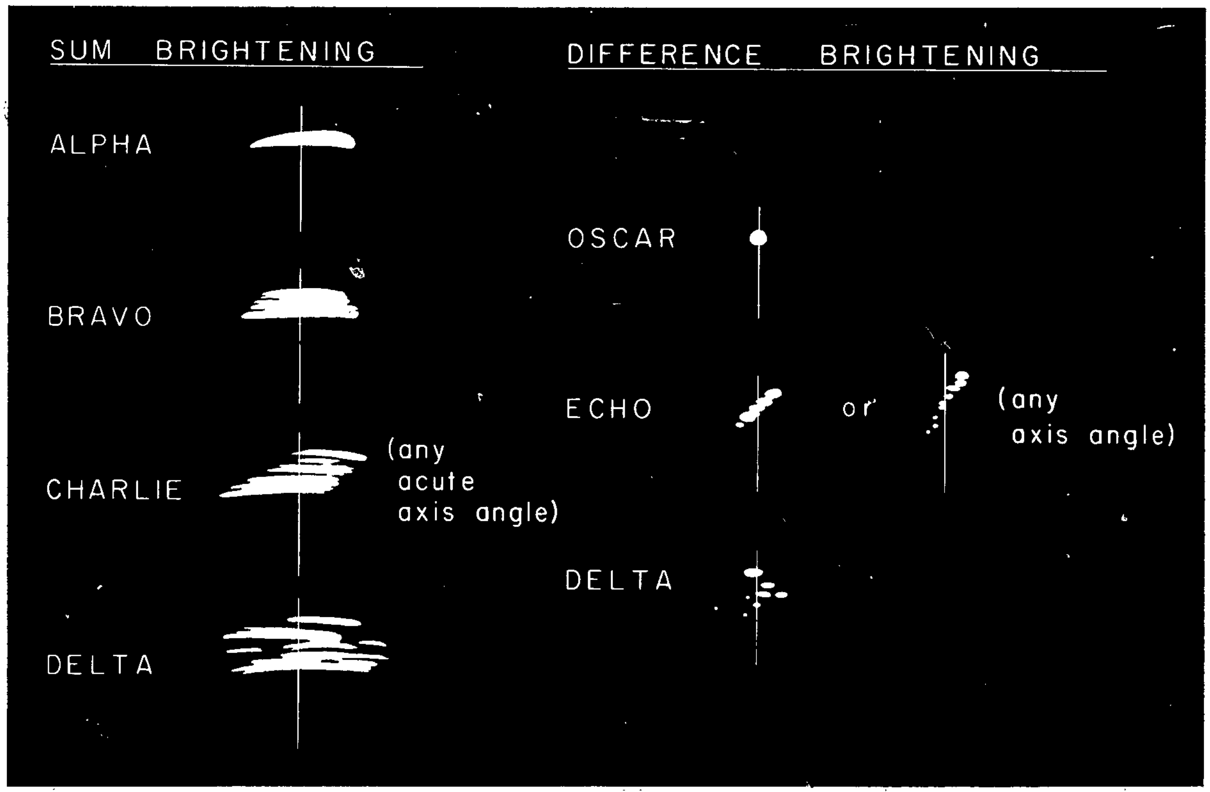

Figure 3. Minimum comprehensive set of sum and difference brightening pip shape categories (Mackie, Gavin and Parker, 1959).

The PPI input panel of the original MITEC (Mk 1 Mod 0) essentially provided for all of the pip shapes listed in Figure 3 plus some minor extensions required by the introduction of the target centered display feature (TCD) of the later sonars. A portion of the input panel is depicted in Figure 4 showing provision for inputs using either sum or difference brightening. Because of the assumed correspondence between pip shapes, single buttons were employed for either sum or difference operation that reflected the anticipated relationships. In operations at sea, however, the correspondence was far from perfect so in later models separate input buttons were created for the two brightening modes.

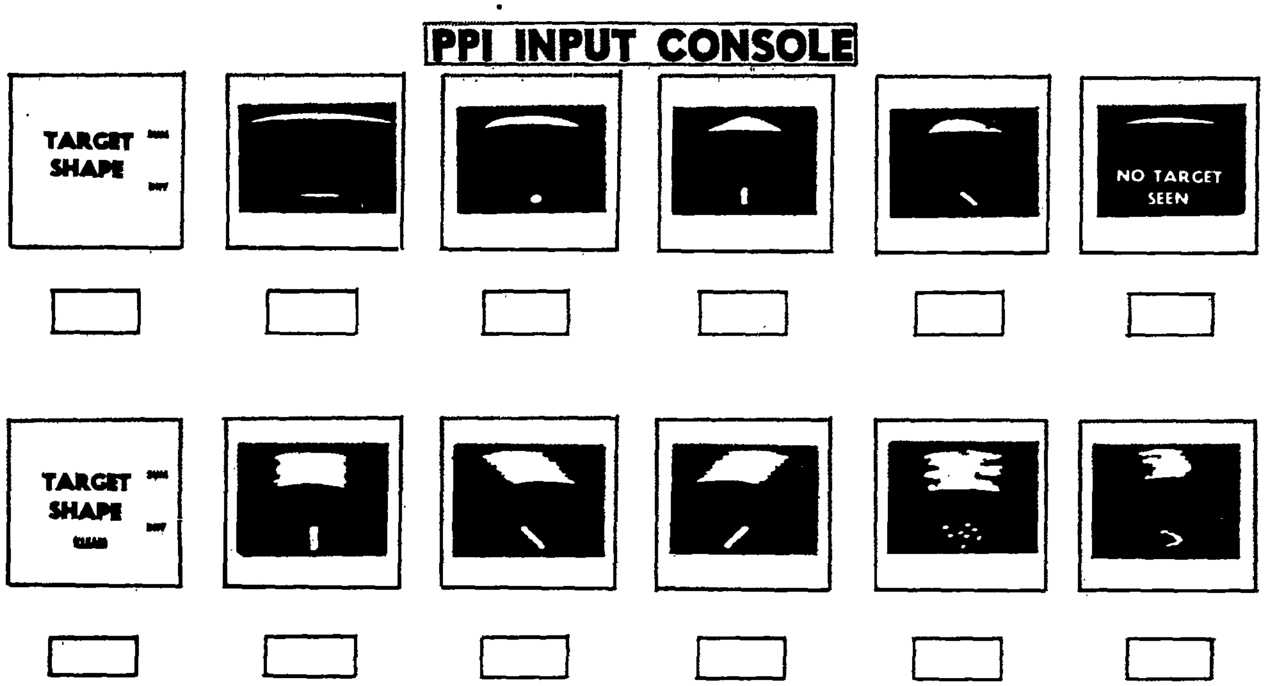

Figure 4. Pip shape configurations employed in the MITEC (Mk 1 Mod 0) sonar target classification aid.

Suspected Shortcomings in the Pip Shape Descriptions

The extreme variability and dynamic character of pip shapes as they are actually displayed on the PPI make it difficult to design an input panel for a classification aid that closely matches perceptual experience at the sonar display. For the same reasons it is very difficult to develop adequate training materials for target classification short of actually photographing the displays or making high fidelity tape recordings.

In the course of analyzing clues presented by RDT-modified and SQS-23 equipment, the conviction grew, however, that qualitative changes had occurred in the difference brightening pip shapes that were adding to the perceptual matching problem. If this were so, the judgments of pip shapes by sonar operators might suffer from the lack of an adequate descriptive framework. Further, if the shapes (or some of them) were in fact different, the basic question of their significance for classification required answering.

The purposes of the present investigation, then, were as follows:

(1) To determine whether the pip shape categories described in previous studies* and used in the Mk 1 Mod 0 MITEC were adequate for judging the pips produced by RDT-modified and SQS-23 sonar.

(2) If the answer to (1) were negative, to develop a new set of categories that would describe the displayed shapes adequately.

(3) To determine the significance for classification of each shape category found necessary. This included such considerations as frequency of occurrence, likelihood of being produced by submarine and non-submarine targets, and, where the target was a submarine, relationship of pip shape to target angle.

*Including NAVPERS 12702.

III. PROCEDURE AND RESULTS

Determining the Adequacy of Previous Pip Shape Categories

Stimulus Materials

The stimulus materials consisted of a comprehensive set of 1217 still photographs of SQS-4 and RDT-modified (SQS-32) PPI target presentations and 2390 16mm motion picture frames of similar SQS-23 presentations. The photography faithfully reproduced pips from a substantial variety of nonsubmarine contacts and from submarine targets at all major aspects. The number of each type of stimulus used is presented in Table I.

Table I

Number of Pip Pictures Used According to Target Nature, Type of Sonar and Brightening Mode

Target \ Sonar	SQS-4 (Diff. only)	SQS-32 (Diff. only)	SQS-23		Total
			Sum	Diff.	
Submarine	268	634	864	341	2107
Nonsubmarine	256	59	632	553	1500
Total	524	693	1496	894	3607

Increased emphasis on difference brightening in both the NEL and HFR classification logic focused major attention on difference brightening in selecting the materials for study. However, some sum brightening returns from the SQS-23 were included to check the hypothesis that there were no important differences in the pips presented through this display mode compared to earlier sonars.

Subjects

Six subjects with experience in perceiving target classification clues served as judges. However, in the interests of economy, only one person judged the SQS-23 material since it was in a form that required viewing on the small screen of a Moviola editing machine. This person also judged the SQS-4 and SQS-32 materials and helped develop the descriptive categories necessary for that material as well as that required for the SQS-23.

Procedure

Each subject first sorted the photographs independently into the categories selected for the input panel of the original MITEC. A few of the perceptually similar categories were combined resulting in the six response categories shown in Figure 5. Pictorial representations were mounted just above appropriate boxes of a sorting board. Subjects were instructed to place each photograph into one of six categories if he felt there was a reasonable match between the pip in the photograph and the pictorial description of that category. He was further instructed to set aside any photographs that were felt to be inadequately represented by the pictorial descriptions on the sorting box. Each subject later sorted these latter photographs into new categories of his own definition which he felt necessary to complete the description of all photographs in the sample. He was also asked to produce a sketch and a verbal definition of each new category employed.

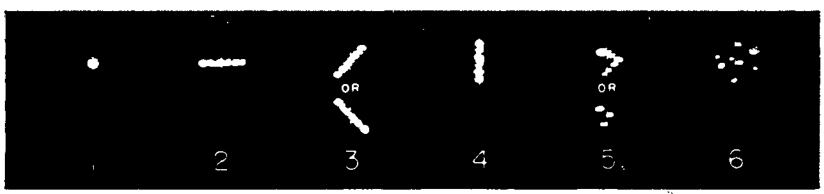

Figure 5. Pictorial representation of pip shape categories used for initial categorical sort. Essentially all categories associated with MITEC Mk 1 Mod 0 were represented.

Results

All subjects found it necessary to invent new descriptive categories to take advantage of the observable differences in the photographs. This was true of the material generated by all three sonars represented in the sample: SQS-4, SQS-32, and SQS-23. However, the new categories, while perceptually different from earlier ones, appeared to be either extensions or variations on the original ones and logically related to them. The new categories, together with the original ones to which they were expected to be related, are shown in Figure 6.

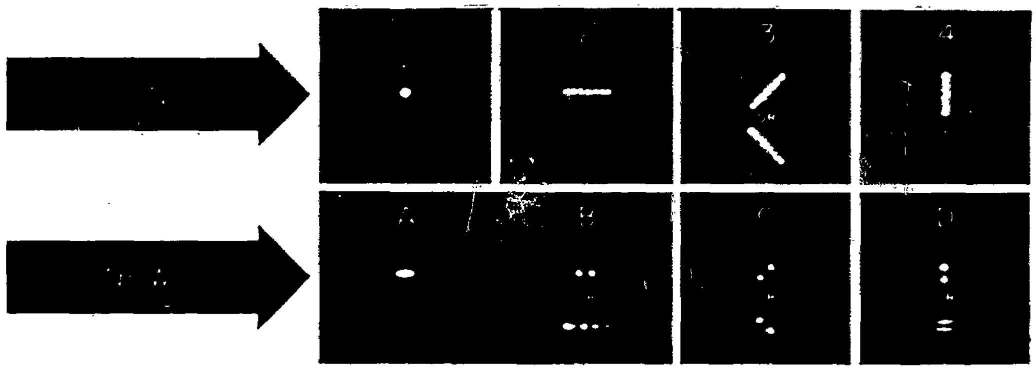

Figure 6. New categories defined by the judges, and related original categories.

Category A, independently developed by 5 of the 6 judges, provides an intermediate description between original Categories 1 and 2. Clearly the extent of pip elongation at approximately right angles to the cursor is the factor determining which category is appropriate. In all three categories the pip has a solid cohesive appearance.

Category B, also independently developed by 5 of the 6 judges, represents further variations on original Category 2. The axis angle again is orthogonal to the cursor but now the pip is broken into two or more small distinct subsegments with no apparent main body.

Category C was felt to be necessary by all 6 judges. It is clearly related to original Category 3, the imaginary axis through the pips making an acute angle with the cursor. Again two or more subsegments are in evidence and the pip has no cohesive main body.

Category D was independently developed by 4 of the 6 judges and is clearly related to original Category 4. In the case of these categories an imaginary axis can be drawn through the pip, or its segments, that is parallel, or coincident with, the cursor. Again it differs from its original counterpart mainly in its lack of cohesiveness, two or more subsegments being clearly identifiable.

Frequency of Use of Each Category

One criterion of the necessity of new descriptive categories, as well as the retention of old ones, is the frequency with which pip shapes of each type occurs in practice. This question is difficult to answer in any absolute sense because the shapes that appear on a particular operating PPI are a function of many variables including target nature, range and aspect, sonar conditions, centering mode, and calibration of the equipment. The use of each category can be justified, however, if it can be shown that pips of each description occur with any regularity at all.

Counts were made, therefore, of the frequencies with which the photographs of SQS-32 and SQS-23 difference brightening pips fell into each of the 10 categories established from the sorts. For this purpose each photograph was categorized according to the modal response of the six judges. The resulting data are presented in Figures 7 and 8 broken down by range scale in use. The 6 original categories and the 4 new ones have been arranged in a logical sequence (according to the presence and orientation of axis angle) and labels have been attached that correspond to those reported in

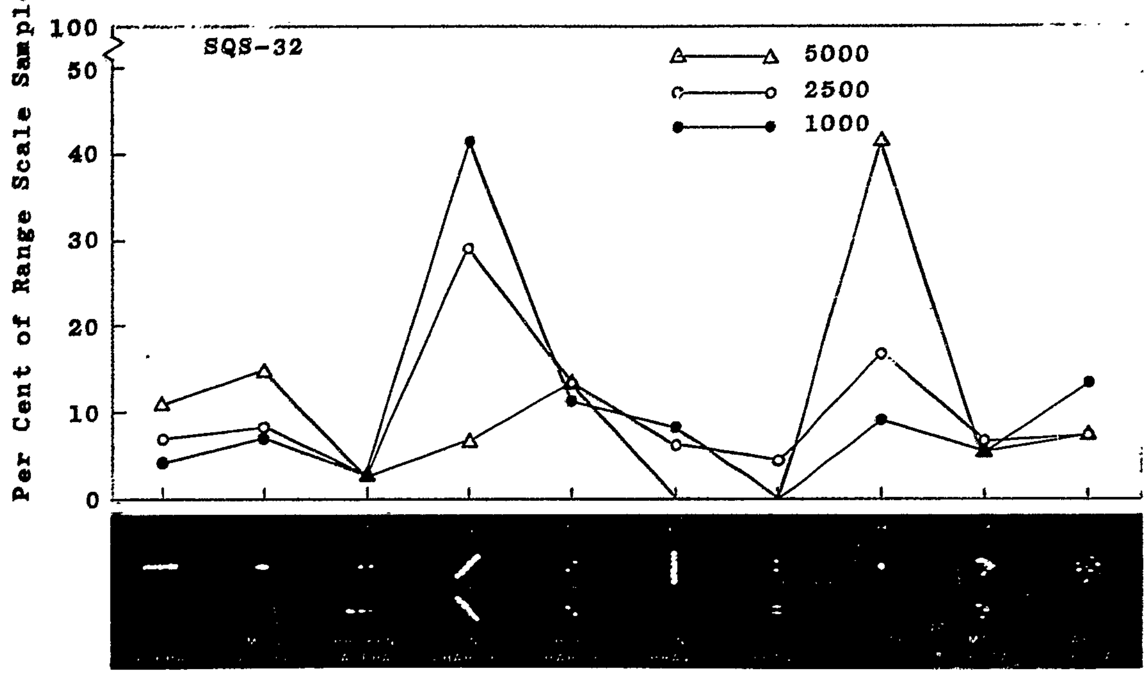

Figure 7. Frequency of use of each category by range scale: SQS-32.

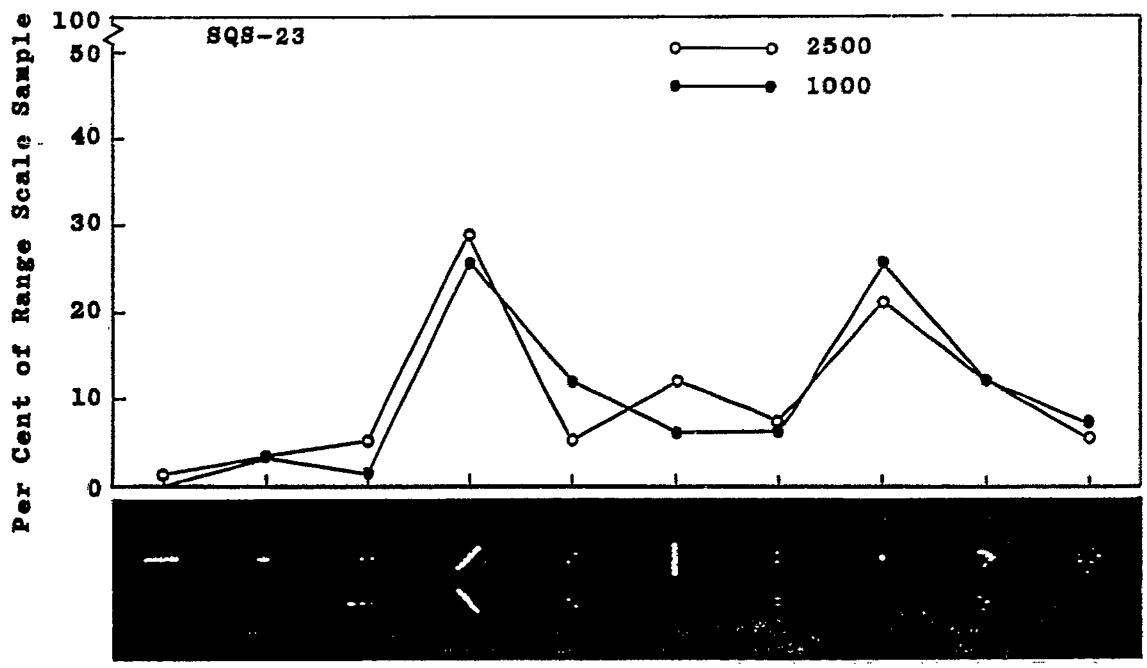

Figure 8. Frequency of use of each category by range scale: SQS-23.

NAVPERS 180581). Data for the 5000-yard range scale of the SQS-23 are not reported because virtually all of the target pips on the longer range scales of the SQS-23 sample were obtained using sum brightening.*

Comparison of Figures 7 and 8 reveals that the most frequently encountered shapes for both sonars were Categories 4 (long CHARLIE) and 8 (OSCAR). CHARLIEs occurred much more frequently on the shorter range scales while OSCARs predominated on the long one. A clear relationship is indicated between range scale in use and the probability that a CHARLIE or OSCAR pip will be displayed. Since these particular pip shapes have classification significance (see page 24), this is an important result for classification logic.

ALPHA pips (Categories 1, 2, and 3) occurred with considerable frequency in the SQS-32 sample but less often with the SQS-23. This may reflect a sampling bias in the data or, possibly, the changed technique for generating difference brightening in the SQS-23 and resultant reduction of the pip's size and shape toward the OSCAR category. In any event, ALPHAs remain a principal shape produced by submarines at beam aspect (as well as by other targets) and retention of the three variations appears to be justified based on frequency of usage from the two sonars combined.

BRAVOs (Categories 6 and 7) appeared with reasonable frequency on both sonars although they are a comparatively short-range phenomenon. It is likely that they degenerate into OSCARs on the 5000-yard and longer range scales. BRAVOs are related to target aspect when the target is a submarine but their association with

*It is very difficult to obtain anything other than Category 8 (OSCAR) pips on the longer range scales of the SQS-23 using difference brightening. In many cases the pip is so small as to be obscured by the cursor and thereby made difficult to track. Consequently sum brightening had to be frequently employed during data collection.

nonsubmarine targets is also strong.

DELTAs (Categories 9 and 10) also occurred with substantial frequencies on both sonars. These targets display either multiple or curvilinear axes and traditionally have implied the presence of a nonsubmarine target. In some instances they are produced by submarines, however, it seems that the target can be at almost any aspect when these shapes are produced.

Effects of Centering Mode on Shape

Since the employment of target centered display (TCD), multiplies the displayed target area by a factor of 2 1/2, it is reasonable to expect the frequency with which certain pip shapes occur to be different using TCD than using SCD (ship centered display). This hypothesis was explored with the results depicted in Figures 9 and 10.

It can be seen that for the SQS-32 there was an appreciable difference in the pip shapes displayed under the two conditions. The frequency of OSCARs (Category 8) dropped markedly when a shift from SCD to TCD was made. Evidently the change operated to produce a greater number of CHARLIEs (Categories 4 and 5) and to increase the display of information useful for classification.

A comparable result cannot be shown for the SQS-23. The incidence of OSCARs was about the same in both centering modes and a consistent increase in CHARLIEs could not be shown. As far as the other shapes were concerned, there appeared to be no important differences associated with centering mode for either sonar.

Relationships Between Pip Shape and Target Nature

The photographs in each of the 10 descriptive categories established by the sorting procedure next were divided according to whether the pips had been produced by a submarine or nonsubmarine

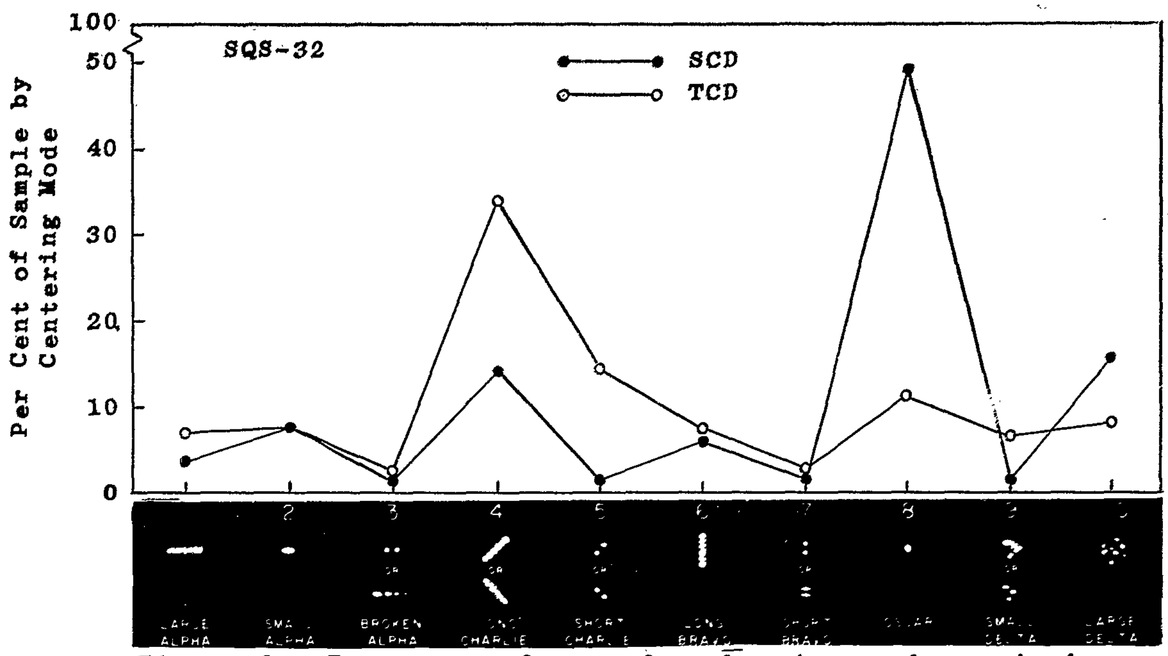

Figure 9. Frequency of use of each category by centering mode: SQS-32.

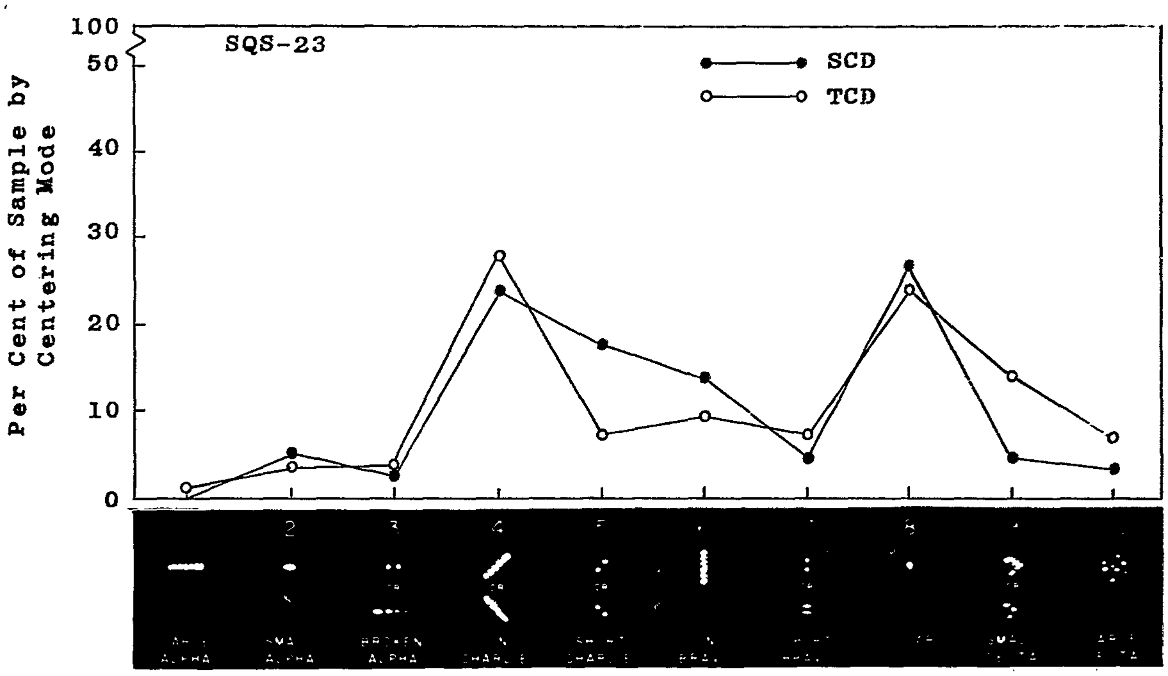

Figure 10. Frequency of use of each category by centering mode: SQS-23.

target. For each shape category, and each sample of sonar returns, the hypothesis was tested that a relationship existed between target nature and the pip shapes obtained. This was accomplished by a series of chi-square tests of the differences in observed and expected frequencies of submarine and nonsubmarine targets falling in each category. The data are reported in Table II along with indications of statistically significant relationships where they occurred.

Hypothesis 1. ALPHA shapes will be produced more frequently by submarines than nonsubmarines.

This hypothesis was substantiated for only one of the three ALPHA shapes (Category 3) and for only the SQS-23 sonar sample where the number of ALPHAs was small. The incidence of ALPHAs was also small in the SQS-4 sample and the highly uneven split between submarines and nonsubmarines in the SQS-32 sample makes the results for that equipment inconclusive. The frequencies in Table II indicate that submarine targets can and do produce the three ALPHA shapes on all of the sonars studied but it is about equally likely that these shapes will be produced by nonsubmarine targets.

Hypothesis 2. CHARLIE shapes will be produced more frequently by submarines than nonsubmarines.

This hypothesis was generally substantiated for Long CHARLIEs (Category 4) but not for Short CHARLIEs (Category 5). The relationship was significant ($p < .01$) for both the SQS-4 and SQS-32 samples but, although in the same direction, it failed to reach significance for the SQS-23 sample. This latter result confirmed the incidental observation of the staff that many more CHARLIE shapes from nonsubmarine targets are obtainable with the SQS-23 than with previous sonars.

Table II. Summary of Relationships Between Target

PIP SHAPE CATEGORY	SQS-4					
	Act. f_{sub}	Exp. f_{sub}	Act. $f_{n/s}$	Exp. $f_{n/s}$	X^2	Direction
1. Large ALPHA	19	16.32	13	15.68	.90	
2. Small ALPHA	13	12.24	11	11.76	.10	
3. Broken ALPHA	3	2.04	1	1.96	.92	
4. Long CHARLIE	86	67.32	46	64.68	10.58**	SUB
5. Short CHARLIE	10	17.34	24	16.66	6.34*	N/S
6. Long BRAVO	27	23.46	19	22.54	1.09	
7. Short BRAVO	5	6.63	8	6.37	.82	
8. OSCAR	61	68.34	73	65.66	1.61	(N/S)
9. Small DELTA	24	26.01	27	24.99	.32	
10. Large DELTA	19	27.03	34	25.97	4.87*	N/S

* $p < .05$
** $p < .01$

Nature and Displayed Pip Shape for Three Sonars

SQS-32						SQS-23					
Act. f_{sub}	Exp. f_{sub}	Act. $f_{n/s}$	Exp. $f_{n/s}$	X^2	Direction	Act. f_{sub}	Exp. f_{sub}	Act. $f_{n/s}$	Exp. $f_{n/s}$	X^2	Direction
42	40.04	2	3.96	1.07		4	1.9	1	3.1	3.74	
51	49.14	3	4.86	.78		10	9.88	16	16.12	.00	
11	12.74	3	1.26	2.64		22	10.26	5	16.74	21.67**	SUB
210	198.38	8	19.62	7.56**	SUB	98	92.72	146	151.28	.48	(SUB)
84	77.35	1	6.65	6.35*	SUB	22	27.36	50	44.64	1.69	(N/S)
43	43.68	5	4.32	.12		48	31.54	35	51.46	13.86**	SUB
15	13.65	0	1.35	1.48		18	22.04	40	35.96	1.19	
94	103.74	20	10.26	10.26**	N/S	50	82.08	166	133.92	20.22**	N/S
35	33.67	2	3.33	.58		52	40.28	54	65.72	5.50*	SUB
49	58.24	15	5.76	16.29**	N/S	17	21.66	40	35.34	1.62	(N/S)

Contrary to the hypothesis, for the SQS-4 sample there was a significant ($p < .05$) relationship between Short CHARLIE shapes and incidence of nonsubmarine targets. The trend was also in this direction for the SQS-23 sample. The relationship was reversed for the SQS-32 sample, however, and reached significance ($p < .05$) in spite of the uneven split between types of targets. This inconsistency between sonars leaves doubts as to the role chance or unidentified systematic factors played in establishing the observed relationships. On the basis of present evidence it must be concluded that Short CHARLIEs have no particular meaning for target classification.

Hypothesis 3. BRAVO shapes will be produced more frequently by submarines than nonsubmarines.

This hypothesis was supported only for Long BRAVO (Category 6) and only for the SQS-23 sample. Results were in the same direction for the SQS-4 sample and completely inconclusive for the SQS-32.

Short BRAVOs appear to be equally likely to have been produced by submarines and nonsubmarines. None of the relationships was significant and the trends were inconsistent. It must be concluded that, for BRAVO shapes in general, there is little of direct significance for classification.

Hypothesis 4. OSCAR shapes will be produced more frequently by nonsubmarines than by submarines.

This hypothesis was generally supported by the data. Although significance was not achieved for the SQS-4, the trend was in the predicted direction. For both the SQS-32 and SQS-23 samples highly significant relationships were found ($p < .01$). In a later section (see below) it will be shown that the relationship is even stronger if the variable of target range is accounted for.

<u>Hypothesis 5</u>. DELTA shapes will be produced more frequently by <u>non</u>submarines than by submarines.

This hypothesis was generally supported for Large DELTAs (Category 10) but not for Small DELTAs (Category 9). Large DELTAs were significantly related to nonsubmarine targets for the SQS-4 sample ($p < .05$) and the SQS-32 sample ($p < .01$). It was in the same direction for the SQS-23 sample but failed to reach significance.

The relationships were inconsistent for Small DELTAs, but a significant association ($p < .05$) with <u>submarine</u> targets was observed in the SQS-23 sample. The reasons for this latter result are not clear. It is possible that the two kinds of shapes called Small DELTAs (:•· and ⊃) have quite different meanings although both can be regarded as having curved (or multiple) axes. The more compact of the two is fairly often seen from submarine targets displayed on the longer range scales. In these cases it is frequently difficult to separate the target echo from surrounding noise echoes. The result is that the total pip regarded as the target has a curvilinear axis even though, considering the target's nature, it should not.

<u>An Interaction Between Pip Shape, Classification Significance, and Range Scale</u>

It was shown in the data on frequency of use of the 10 shape categories that some shapes occurred more frequently on long scale and others on short scale. In part this probably reflects the fundamental ability of the sonar to resolve and display range and bearing displacement in the total target return. It is evident that target range could readily be a variable that would swamp important relationships between target nature and the pip shape displayed.

An adequate test of this possibility requires an enormous amount of carefully collected target data. The fact that there are two brightening modes, two centering modes, several range scales and a multiplicity of possible target ranges makes it a practical impossibility to obtain enough data to reliably establish the relationship for each pip shape category. The large incidence of Category 4 (Long CHARLIE) and Category 8 (OSCAR) pips did permit, however, an exploration of this interaction. To gain some stability, the data from the three sonars were combined in this analysis. This was felt to be justified because the classification significance of these two categories was in the same direction for each data sample. The results are shown in Figure 11.

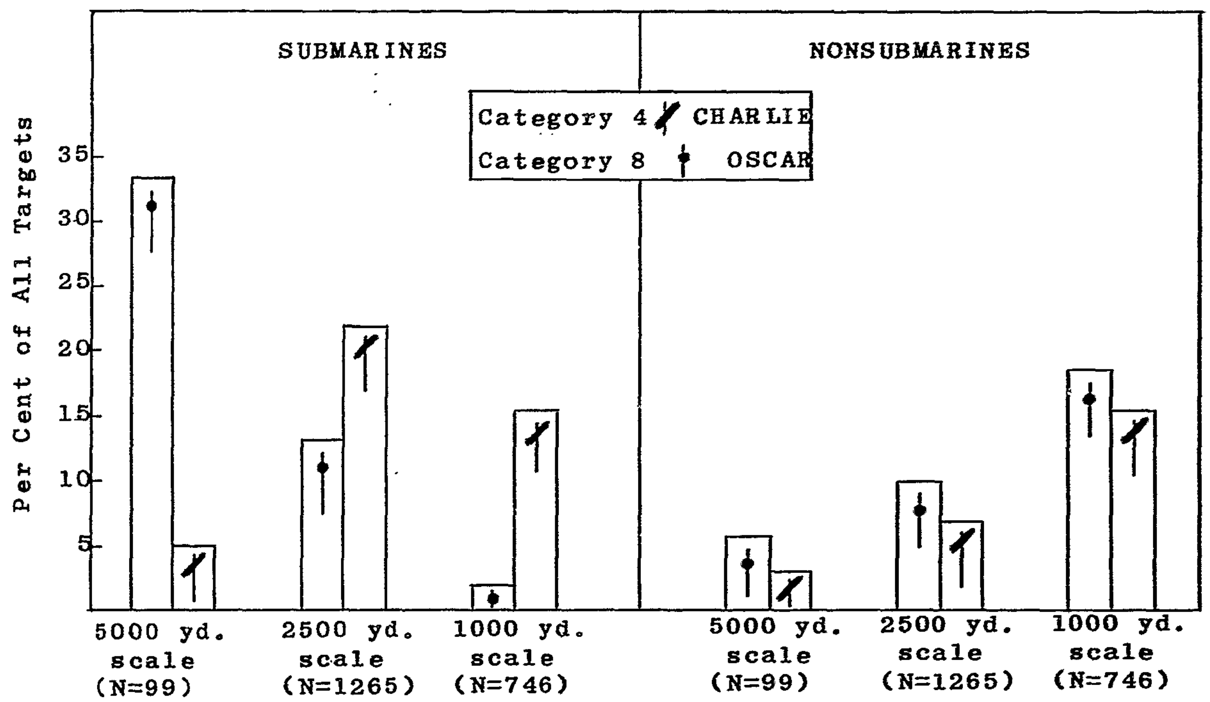

Figure 11. Interaction between frequency of occurrence of two pip shapes, range scale, and target nature.

It can be seen that for submarine targets the likelihood of obtaining OSCAR pips varied directly with the range scale in use. It was the predominant shape on the 5000-yard scale but rarely occurred on the 1000-yard scale. Conversely, the likelihood of obtaining CHARLIE pips from submarines was very low on the 5000-yard scale but appreciably greater on the shorter range scales. The slight reduction in frequency of CHARLIE pips on the 1000-yard scale, rather than the possibly expected increase, was due almost entirely to the SQS-23 portion of the data. For whatever reasons, considerable break-up and misalignment of the pips from close range submarine targets occur with this sonar.

The trends were quite different for nonsubmarine targets. In this case the frequency of OSCAR pips was inversely related to range scale. If the relative frequencies of OSCAR pips on the 1000-yard range scale are compared for submarines and nonsubmarines it is evident that a powerful classification relationship is involved. Unfortunately the same kind of relationship does not hold for CHARLIE pips on the 1000-yard scale although it does obtain for the 2500-yard scale.

It is difficult to establish the reliability of interactions of this type in the absence of vast quantities of data collected under many conditions. It is clear from this example, however, that the variable of target range (or equipment range scale) affects the displayed pip shapes in such a way as to make the relationships between pip shape and target classification very complex. The development of sound classification logic and procedures requires knowledge of these relationships.

Relationships Between Pip Shapes and Target Aspect

Despite the lack of substantial direct relationships between pip shape and target nature, considerable information of value to classification would be obtainable from the PPI if it could be shown that the axis angle of the pips was systematically related to the aspect of submarine targets.

Target aspect was accurately known for about 95% of the photographs in the three data samples. To answer the present question, these were divided according to whether they had been produced by submarines at (1) beam aspect; (2) quarter or broad bow aspect, or (3) stern or direct bow aspect. Since target heading is rarely discernible on the PPI from pip shape information alone, there was no advantage in employing something more than this basic trichotomy. All targets that were more than 10° off the beam, or more than 10° off direct bow/stern, were classified as bow or quarter targets as appropriate.

The photographs in each of the three aspect categories were next sorted according to the pip shape displayed and frequency counts were made. The resulting data are shown in Table III. The different kinds of ALPHA, BRAVO, and CHARLIE shapes have been combined in this analysis since the same axis angle judgment would be appropriate regardless of the variation displayed.

ALPHA pips are seen to have been rarely produced by submarine targets at any aspect other than beam. Roughly 40% of all beam aspect targets in each data sample produced ALPHA pips. These targets also produced other pip shapes, however, notably CHARLIEs and OSCARs. It is probable that many of the CHARLIEs were actually from targets slightly off the beam while OSCARs, as previously noted, can be expected as a function of long range. The incidence of OSCARs was particularly high (40%) for the SQS-23 sample but most of these pips came from the 2500- and 5000-yard range scales.

BRAVO pips were produced almost solely by submarine targets at either direct bow or direct stern aspect. However, for the SQS-32 sample about the same percentage of CHARLIEs was produced. The only apparent reason for this is that some of the runs involved

Table III

Percentage of Echoes from Submarines at Three Basic Aspects Displaying Various Pip Shapes (For SQS-4, SQS-32 and SQS-23 Sonars)

		ACTUAL TARGET ASPECT								
		Direct Bow/Stern			Bow/Quarter			Beam		
	Sonar/SQS	-4	-32	-32	-4	-32	-23	-4	-32	-23
Shape	Axis Orientation	N=28	N=92	N=114	N=169	N=352	N=177	N=29	N=84	N=53
ALPHA	Right angle	00	08	01	08	12	07	41	39	43
BRAVO	Coincident with cursor	43	28	52	10	04	04	00	08	00
CHARLIE	Acute angle	14	29	05	43	57	63	28	20	02
OSCAR	No axis	29	16	12	21	15	09	25	17	40
Small DELTA	Curved axis	14	08	26	08	06	12	03	06	06
Large DELTA	Multiple axis	00	11	04	10	06	04	03	10	09
	Total	100	100	100	100	100	100	100	100	100

a changing aspect target and consequently the correspondence between its computed (from plot) and actual aspect may have been imperfect. The incidence of other pip shapes for bow/stern targets was non-systematic. A few OSCARs were expected because of the target range factor. The appearance of Small DELTAs, particularly in the SQS-23 sample, may reflect sporadic returns, or interference from, the target's wake at these aspects.

CHARLIE pips were produced in the main by targets at bow or quarter aspects. A small percentage of CHARLIEs was produced by beam and direct bow/stern targets but it is notable that they rarely occurred in the SQS-23 sample in which target aspect was determinable with the greatest accuracy. No other target shape was produced systematically by submarines at bow or quarter aspects. A few OSCARs and Small DELTAs occurred with particular sonars, probably for reasons already discussed.

As might be expected, OSCAR pips were produced a fair percentage of the time by submarine targets at all aspects. The vast majority of these occurred on the longer range scales and simply reflect the limited range and bearing resolution of present signal processing and display techniques.

DELTAs, both large and small, were infrequently produced by submarine targets regardless of aspect. The single notable exception was the substantial number of Small DELTAs produced from direct bow/stern targets by the SQS-23. This may have been an accident of sampling or it may reflect periodic returns from target wake, a distinct possibility at least with stern targets. Many of these pips were produced by targets on the 2500-yard scale using target centered display. Perhaps under these conditions random reflectors near the main target body were difficult to separate from it perceptually. This could result in the display of pips that apparently have curvilinear axes.

In general the results of this portion of the study are encouraging for target classification. Targets at each aspect studied are most likely to produce pip shapes whose axes correspond to that aspect. There will be variability, of course, and there are important limits on the range at which a target will display any axis at all. On the other hand, submarine targets rarely display multiple axes and infrequently display curved ones.

Nature and Significance of Sum Brightening Pip Shapes on the SQS-23

Incidental observation had suggested that there were no important differences between the sum brightening shapes displayed by the SQS-23 and those of earlier sonars. The decision was made to test this hypothesis by sorting 1496 PPI photographs of SQS-23 sum brightened pips, as displayed on a Moviola, into those shape categories previously established for MITEC (see Figure 4). This was done by one experienced observer. Again the instructions were to create new descriptive categories whenever the match between existing categories and the displayed shapes was felt to be inadequate.

It will be recalled that most of the longer range targets in the SQS-23 sample were recorded in the sum brightening mode because of the inability to track long range targets effectively in difference brightening. Consequently the sum brightening data sample had something of a "long-range" bias corresponding to the "short-range" bias of the difference brightening sample. Not too much importance can be attributed to the relative frequencies of various pip shapes observed, therefore, but some interesting relationships between shape and target nature did obtain.

The results of this portion of the study are presented in Table IV. It was found that, while previous descriptions of sum brightening pip shapes were generally appropriate for SQS-23 echoes, a number of variations on the original ones was also

Table IV

Sum Brightening Pip Shapes Related to Range Scale, Centering Mode and Target Nature (SQS-23 only)

Designator	Shape	Range Scale				Centering Mode		Target Nature		X2	Direction
		10,000	5000	2500	1000	SCD	TCD	Sub	Nonsub		
1. Small ALPHA (N=656)		27	234	363	32	599	57	417	239	8.34	S >.01
2. Large ALPHA (N=280)		24	45	187	24	112	168	214	66	39.04	S >.01
3. Short BRAVO (N=214)		1	31	165	17	201	13	80	134	37.30	NS >.01
4. Long BRAVO (N=187)		-	-	80	107	39	148	72	115	29.25	NS >.01
5. Short CHARLIE (N=33)		-	3	17	13	32	1	21	12	0.45	Not Sig.
6. Long CHARLIE (N=120)		4	-	23	93	21	99	59	61	3.84	NS >.05
7. DELTA		-	-	-	6	0	6	1	5	-	-
	N=1496	56	313	835	292	1004	492	864	632		

helpful for making the required perceptual matches. In general, it proved helpful to divide ALPHA shapes into "small" or "large" based primarily on angular width and to divide BRAVO and CHARLIE shapes into "short" or "long" based primarily upon radial extent.

It will be noted that similar designators have now been adopted for sum and difference brightening shapes and that there is a direct correspondence between the imagined axis angle, if any, for pip shapes having corresponding designators. The only exception to this rule occurs with sum brightening on the longer range scales (5000 yards and over) where a target at any axis angle is most likely to display an ALPHA pip.

Small ALPHA

This was the predominant shape displayed by all targets on the longer range scales. It also occurred with high frequency on the 2500-yard scale particularly with ship centered display (SCD). In general Small ALPHAs occurred more often with submarine than non-submarine targets but again there was an interaction with range scale. The odds that a Small ALPHA was produced by a submarine target were highest on the 5000-yard scale, somewhat lower on the 2500-yard scale, and were actually reversed in favor of nonsubmarine on the 1000-yard scale.

Large ALPHA

Although this shape appeared on all range scales it was more likely to occur on the shorter ones and particularly when target centered display (TCD) was in use. Large ALPHAs were more strongly associated with submarine targets than Small ALPHAs and it is notable that virtually all Large ALPHAs that appeared on the 5000- and 10,000-yard range scales were submarine echoes. The extent to which this result is sample specific is, of course, unknown.

Short BRAVO

As with difference brightening, the elongation of sum brightening shapes occurs infrequently until the shorter range scales can be employed. Short BRAVOs occurred most frequently on the 2500-yard scale using SCD. They practically always became Long BRAVOs if a shift to TCD was made. In this sample Short BRAVOs were more frequently produced by nonsubmarines than by submarines. This relationship must be interpreted with caution, however, since the sonar set was sometimes operated in sum brightening on the shorter range scales only when the target was not adequately displayed in difference brightening. This would be more likely to occur with nonsubmarine targets that were relatively poor reflectors. Thus the relationship could be an artifact of operating technique.

Long BRAVO

The Long BRAVO is essentially the TCD counterpart of the Short BRAVO and was likely to occur only on the shorter range scales. It also was produced significantly more often by nonsubmarines than by submarines, but, for the reason advanced above, the relationship must be regarded as tenuous. In the difference brightening counterpart of this sample, Long BRAVOs were produced significantly more often by submarines.

Short CHARLIE

This shape was strongly associated with SCD operation on the shorter range scales. The present sample is too small to make any inferences about its significance for classification other than the opportunity it affords to make an estimate of the target's axis angle.

Long CHARLIE

Long CHARLIEs appear to be the TCD counterpart of Short CHARLIEs although they did appear fairly often with SCD as well. In this sample they were produced more often by nonsubmarines than by submarines, a finding in contradiction to results on earlier sonars. Again, because of small sample size, possible operational artifacts, and the lack of a similar relationship for difference brightening, the result must be interpreted with caution.

DELTA

The interesting finding about this pip shape is that it practically never occurred with the SQS-23. When it did, it was a short-range phenomenon. This too could have been an operational artifact since there was a fair number of DELTAs that occurred with difference brightening. However, it also seems to reflect a greater tendency for the SQS-23 to produce BRAVO and CHARLIE pips from targets that, in actuality, did not possess a single, linear axis.

IV. DISCUSSION AND CONCLUSIONS

It is clear from the results of this investigation that little direct dependence can be placed upon the displayed PPI pip shape for purposes of target classification. Virtually every pip shape that is obtainable from a submarine is also obtained upon occasion from a variety of nonsubmarine targets. Further, there are no pip shapes that are the exclusive property of nonsubmarine targets although some of them apparently are rarely obtained from submarines at close range and some are rarely obtained from nonsubmarines at long range.

The substantial relationship between pip shape and target aspect on the other hand is critically important to target classification because of the basic dependence of present classification logic on the indicated target aspect. The correlation of aspect indications from the audio, PPI, and graphic displays, or the lack thereof, is frequently a powerful clue to classification. It is unfortunate that present PPI displays provide such limited evidence of target axis except at comparatively short ranges. Any improvement in the processing of sonar signals that would enhance the display of the PPI pip's apparent axis would materially improve target classification. This is particularly true for difference brightening which is the superior mode of operation for effectively judging axis angle. Little or no progress appears to have been made in the display of this kind of information since the development of the first scanning sonars.

The present study has re-established the need and significance of both old and new pip shape categories in conveying the information displayed by contemporary equipment. It is important, both for training purposes and for the design of classification aids, that a minimum of error be introduced through the perceptual requirement to match the displayed pip shape with pictorial descriptions of shapes having known significance for classification.

It is believed that the expanded descriptions of difference brightening pips developed through this investigation represents an improvement over earlier descriptions. This does not mean that the perceptual matching task will be an easy one. It is likely that considerable training will be required before effective matching is achieved by the average sonar operator.

Training is complicated by the fact that, in practice, a target does not display a single shape during a sequence of echoes but rather a considerable variety. The task of the operator then becomes one of reporting the shape that most frequently occurs, or, in some cases, the one that is most significant. On occasion, he may have to differentially weight some pip shapes in contrast to others. This requirement occurs when the target pip is incomplete on some returns due to various sources of interference. An echo reflecting the full extent of the target obviously has greater meaning than one obtained from only a portion of the target and must be weighted differentially in arriving at a summary judgment.

It is possible that the conclusions of this study are conservative with respect to the value of PPI pip shapes in target classification. The questions concerning their direct classification significance, and indirect significance through the display of axis angle, were answered by studying photographs of individual pip shapes produced by single echoes. The variability inherent in sonar returns would suggest that many of these echoes were, in fact, only partial ones. During a sequence of returns, the human observer can compensate for incomplete returns and possibly obtain information from the sequence that is not obvious in the individual echo. In psychological terms the whole may well be greater than the sum of its parts. The problem of the effects of sequence variability on a composite judgment for that sequence is a difficult one that has not received much attention to date.

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